

Hydrothermal Activity in the Lau Basin

First Results From the NAUTILAU Cruise

The Nautilus Group

The Lau Basin, a back arc spreading center, is one of the most active hydrothermal areas in the ocean. A scientific team from France, Germany, and Tonga investigated the southern Lau Basin near Tonga in 1989 to study the processes of seafloor ore-mineral formation associated with hydrothermal circulation along the volcanic Valu Fa ridge (Ride de Valu Fa in Figure 1), which lies in back of the Tonga-Kermadec trench.

Between April 17 and May 10 scientists on the R/V *Nadir* used the submersible *Nautilus* to make 22 dives in the southern Lau Basin. The cruise was called NAUTILAU, for *Nautilus* in Lau Basin. In addition to the standard equipment of the submersible (video and photo cameras, and temperature probe), a CTD (conductivity-temperature-depth) instrument was integrated with a "mini rosette" water sampling device used for the first time on the *Nautilus* to obtain correlations between the geological observations and the physical and chemical anomalies measured in the seawater.

A primary result of the cruise is the first observation of an active black smoker hydrothermal field in a back arc environment. In addition, many fossil deposits were found. The deposits differ in mineralogy and geochemistry from deposits of oceanic ridges. Many tectonic observations were made and volcanic rocks were collected all along Valu Fa ridge.

Geological Environment

Valu Fa ridge is the active back arc spreading center of the southern Lau basin [Morton and Sleep, 1985]. Its strike length is about 150 km; the Tofua volcanic arc is only 40 km to the east. The ridge is divided into northern, central and southern segments. Highly fractionated suites of Fe-Ti basalts, andesites, dacites, rhyolites are found along the southern segment [Jenner et al., 1987; Vallier et al., 1988; von Stackelberg et al., 1988; Frenzel et al., 1990].

Selection of the four diving areas (boxes, Figure 1), located on Valu Fa ridge between 21°25'S and 22°40'S at a depth of about 2000 m, was based on results of the cruises of R/V *Jean Charcot* and R/V *Sonne* [von Stackelberg et al., 1988, 1990; Foucher et al., 1988].

Summary of Results

The cruise confirmed the differences between Valu Fa ridge and the spreading ridge

segment of the northern part of the Lau Basin.

- Valu Fa ridge is located at the eastern side of the basin, while the northern spreading axis of the Lau basin is in the middle of the basin. Valu Fa ridge is comprised of many segments and is complicated in detail. Many, more or less active, secondary ridges and volcanoes are located between the ridge and the active island arc.

- The most important difference is the petrology of the collected rocks, which constitute a differentiated series including basalt, andesite, dacite, and rhyolite. All these rocks are highly vesicular and autobrecciated, and indicate a high volatile content in the magma. In three different areas on the flank of the ridge we have observed outcrops of pumice.

- A major discovery was hydrothermal activity in all four study areas. The evidence was widespread occurrence of hydrothermal deposits, and heat flow and CTD anomalies near the sea bottom. The most spectacular findings were white and black smokers and associated fauna and ore deposits.

Tectonic Activity Along Valu Fa Ridge

The smooth rounded morphology of the southern and central ridge segments is thought to be generated by intense alteration and decay of rocks, caused in part by the widespread hydrothermal activity. Therefore,

we do not expect the dynamics of ridge formation to produce the same faults and offsets at the seafloor as can be expected in massive volcanic rocks. We conclude that the particular rock type and hydrothermal activity of these ridge segments effectively masks many of the tectonic features.

Tectonic features are much less restricted to the crest in the northern segment. Ridge-parallel normal faults have vertical offset as great as 60 m. Fissures and small grabens clearly indicate extensional tectonism. However, faults perpendicular to the ridge have also been seen, and schistose volcanic rocks along some major faults indicate a compressive component in the regional stress field.

Two secondary ridges were studied, east of Valu Fa at the northern end of the northern segment. Recent activity has occurred at these parallel structures. This raises a question about the location and distribution of tectonic, volcanic and hydrothermal activity. Was volcanism solely confined to Valu Fa ridge or did it affect a broad area encompassing the ridge and the active island arc?

Hydrothermal Deposits

Four types of hydrothermal deposits, represented by 16 occurrences of high- and low-temperature precipitates, were discovered during the cruise. They show variations possibly related to the tectonic behavior of the ridge. Andesites and banded andesites-dacites

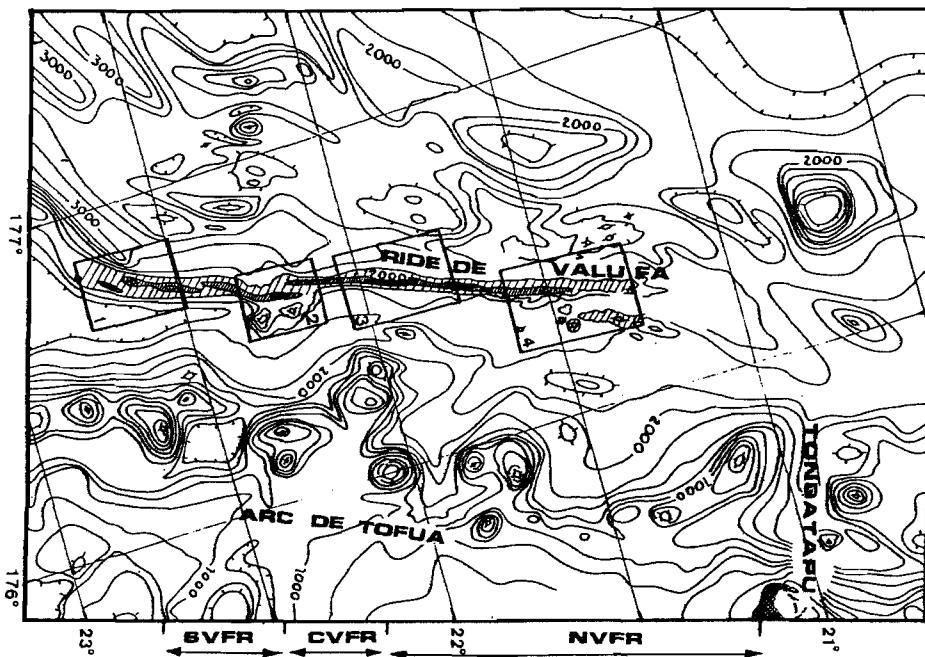


Fig. 1. Map of the part of the Lau Basin studied during the NAUTILAU cruise, April 17-May 10, 1989. Boxes 1, 2, 3 and 4 mark the diving areas.

Cover. Photograph of white smokers in the Lau Basin. Fluid temperatures at this site were between 250°C and 320°C. Chimneys are made primarily of barite, sphalerite and chalcopyrite. The basin, a back arc spreading center in the western South Pacific Ocean west of the Tonga Trench, is one of the most active hydro-

thermal areas in the ocean. The photograph was taken from the submersible *Nautilus* during the French-German IFREMER-BGR cruise April 17-May 10, 1989. See "Hydrothermal Activity in the Lau Basin" in The Oceanography Report, this issue.

are the host rocks of hydrothermal sulfide deposits on Valu Fa ridge, whereas hydrothermal deposits on a seamount a few kilometers east of the central ridge segment are exclusively related to olivine-plus-pyroxene cumulate rocks in which ground mass glasses have basaltic andesite to andesite composition.

Low temperature deposits (40°C). These are related to discharge through highly vesicular and brecciated andesite at a water depth of 1900 m at the southern ridge segment. They are characterized by extensive seafloor deposits of manganese and iron oxide crust. The near-surface rocks show strong alteration and impregnation by sulfides occurring as disseminated crystals or veinlets. In contrast to deposits observed on oceanic ridges, the massive copper-iron sulfides here are not deposited on the seafloor but constitute layered precipitates within the highly altered subsurface oceanic crust.

The mineralogical assemblage indicates that the sulfides were formed at high temperatures. This type of deposit was observed at different locations along the southern ridge segment. Manganese and iron oxide crusts and fields of dead mussel shells extend for several kilometers along the ridge and indicate the widespread occurrence of low-temperature hydrothermal activity. According to our model the extensive occurrence of low-temperature surface and high-temperature subsurface mineralization is explained by the high permeability of the extensive fragmented andesitic seafloor [von Stackelberg *et al.*, 1988; von Stackelberg and von Rad, 1990] and the coverage by iron-manganese crusts. Due to the white color of the altered volcanic rocks, this hydrothermal field was called Hine Hina ("white" in Tongan).

Medium to high temperature barite-sulfide mineralizations. These were observed in many places along the top and on the flanks of the northern Valu Fa ridge segment at water depths between 1960 m and 1800 m. The most important field, a few hundred meters in diameter and 20 m high, consists of barite chimneys up to 15 m high and barite boulders mixed with massive sulfides. The field appears related to normal faults at the eastern flank of the ridge. Along these faults, hundreds of small (up to 50 cm high) manganese chimneys were observed. Thus, tectonic control over the hydrothermal discharge was more clear here than at the southern ridge segment.

Locally, fields of low-temperature hydrothermal discharge occur. The most recent lavas were observed on the eastern flank at the base of the ridge. In contrast to the porous brecciated andesite at the top of the ridge, the basaltic pillow lava is free of any sediment cover. The highest temperatures in expelled fluids were 25°C.

Very high temperature black and white smokers. These were discovered at the central ridge segment. Temperatures measured in the black smokers varied between 320°C and 400°C; fluid temperatures at the white smokers were between 250°C and 320°C. The temperature anomaly in the surrounding near bottom seawater (up to 30°C) suggests that this spectacular hydrothermal field is one of the most active known in the oceans at the present time.

In the active area a complete cross section through a massive sulfide deposit was carried out from the top to the base, and we have

successfully observed active black smokers, talus of broken copper and zinc chimneys, porous zinc sulfides, massive zinc-rich sulfides, massive copper-rich sulfides, and stockwork mineralization in altered andesite showing centimetric veins of chalcopyrite. The active zone is 400 m long and 100 m wide and seems to be controlled by ridge-parallel normal faults. Hydrothermal manganese crusts were observed on the seafloor around this active zone. This hydrothermal field was called Vai Lili ("very hot" water in Tongan).

Low-temperature hydrothermal iron oxide and temperature anomalies. These were observed at the top of three off-axis seamounts located a few kilometers east of the northern and central Valu Fa ridge segments. Though there was no visible hydrothermal activity in these areas, all the seamounts show temperature anomalies at their top and on one seamount extensive thick hydrothermal crusts were observed.

Water Chemistry and Physical Measurements

Seabottom samples. A Seabird CTD was used on the *Nauile* for horizontal and vertical profiles. In addition, 120 bottom water samples were collected and analyzed on board for methane, silica and dissolved oxygen. Many samples collected around the hydrothermal field showed silica (up to 2500 $\mu\text{M kg}^{-1}$) and methane (up to 8500 nL l^{-1}) enrichments associated with dissolved oxygen depletion. The results will lead to better understanding of the relationships among hydrothermal inputs (physical and chemical anomalies) and geological features. In the Vai Lili area the plume rises up to 200 m and the CTD recordings show spectacular variations in potential temperature and conductivity. The heat input at Vai Lili places the area among the most active vent fields in the ocean.

Hydrothermal samples. Hydrothermal fluids ranging in temperature from 240°C to 342°C were collected using titanium syringes. After extraction of the gas-phase, pH, sulfate, methane, and silica were determined on board the *Nadir*. With one exception the samples contained more than 90% pure hydrothermal fluid. Onshore analyses showed that all samples had an endmember pH of 2, the lowest yet measured in deep oceanic hydrothermal fluids. The dissolved silica end-members were about Si 14 mM kg^{-1} , with chloride concentrations between 700 and 800 mM kg^{-1} .

Heat Flow Measurement

In area 1 (see Figure 1) the heat flow data indicate that the sediment trough between Valu Fa ridge and the secondary ridge to the east is cool, except that measurements at the axis of the trough may indicate incipient intrusions. The heat flow pattern tends to favor an interpretation of Valu Fa ridge and the ridge to the east as recent volcanic intrusions through the old crust of the Lau Basin. However, the thickness of pelagic sediments on the ridge to the east suggests that volcanic activity may be less recent there than on Valu Fa ridge. Very high flow near Valu Fa ridge suggests upward fluid circulation carrying heat to the sea floor.

In area 4, the geothermal structure east of the northern segment of Valu Fa ridge is relatively simple. Low geothermal gradients are associated with basins filled by sediments, whereas considerably higher gradients were measured on secondary ridges. The most straightforward interpretation of the secondary ridges is therefore in terms of linear magmatic injections through the old crust of the Lau Basin. This interpretation is in disagreement with the concept of Valu Fa ridge functioning as a spreading center for the past million years. One high geothermal gradient of 775°C km^{-1} at a secondary ridge is difficult to reconcile with conductive cooling models of intrusions. It might indicate heat transfer by upward fluid circulation.

Biological Activity

Animal communities surrounding the low-temperature active vent fields were dominated by gastropods (haired snails similar to those found in the Marinas back arc, and a black snail not yet described) and bivalves (mussels related to the species found on the East Pacific rise). Many mollusks, vent fishes, shrimps, cyrripeds, and galatheid crabs were observed. Stalked and sessile barnacles were also found on the rocks, together with some scattered vestimentiferan tube worms. Among these animals, some are new species.

The animals were observed in environments where the temperature varied between 2°C and 40°C. It appears that Valu Fa ridge shows two types of biological assemblages, one clearly related to hydrothermal fluids and a second that resembles communities known from cold water seeps (A. M. Alayse, IFREMER, personal communication). The high-temperature black and white smokers are not associated with abundant vent fauna, and two possible reasons can be suggested. The vent field was just recently reactivated, or the hydrothermal fluids have a high dissolved metal/sulfur ratio that does not favor life.

Conclusion

The cruise participants will evaluate the collected data and samples. The scientific results of the NAUTILAU project will bring

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about better understanding of the tectonic and volcanic activity, hydrothermal processes, and genesis of sulfide ores at modern back arc spreading centers.

The NAUTILAU project is the result of scientific cooperation initiated several years ago between France and Germany. It has been jointly organized and financed equally by both countries. The NAUTILAU cruise, which took place within the Exclusive Economic Zone of Tonga, was planned in cooperation with the government of Tonga and CCOP/SOPAC (intergovernmental Committee for Coordination of Joint Prospecting for mineral resources in the South Pacific Offshore Areas).

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